DETERMINATION AND CORRELATION OF A FEW PROPERTIES OF COAL

A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology
in
Mining Engineering

by

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Under the Guidance of
Dr. MANOJ KUMAR MISHRA

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CERTIFICATE

This is to certify that the thesis entitled “*DETERMINATION AND CORRELATION OF A FEW PROPERTIES OF COAL*” submitted by Mr. Manoranjan Sahoo, rollno-111MN0087 for partial fulfilment of the requirements for the award of Bachelor of Technology degree in Mining Engineering, National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

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My heart pulsates with the thrill for tendering gratitude to those persons who helped me in the completion of the project. The most pleasant point of presenting a thesis is the opportunity to thank those who have contributed to it. Unfortunately, the list of expressions of thank no matter how extensive is always incomplete and inadequate. Indeed this page of acknowledgment shall never be able to touch the horizon of generosity of those who tendered their help to me. First and foremost, I would like to express my gratitude and indebtedness to **Dr. Manoj Kumar Mishra** for his kindness in allowing me for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout this project work. I am sincerely thankful to him for his able guidance and pain taking effort in improving my understanding of this project. I am also grateful to research scholar **Mr. Harinandan Kumar** and **Mr. B.N. Mallick** in Department of Mining Engineering for their assistance and help in carrying out different experiments in the laboratories. An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them. Last but not least, my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this undertaking.

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ABSTRACT

Mining activities of minerals play a very important role on the health and wealth of any nation. Though technology has reduced the adverse effects to a great extent, it is still experiencing unpredictable behaviour of rocks/coal. The cutting tools used for excavation often exhibit breakdown, high wear and tear due to change in the properties of rock/coal materials. There are many attempts to minimise these events and accurate determination of the properties is one of those. The major strength parameter is usually correlated with other parameters determined at field. The present study focuses on the study of different physical parameters of coal from regions of Talcher, IB valley and Jharkhand area. The regions are well known for huge coal mining. In coal mining operations we deal mainly with differentmechanical properties and its varying strengths since mining methods hugely depends on it. Research in geology and rock mechanics is done to elucidate the influence of the rock index properties in determining the strength, durability, crushability and nature of the rock. This project throws light on the prediction of the coal behaviour and nature of it, by finding a correlation between them. Unconfined Compressive Strength, density, Protodyakonov Strength Index and ultrasonic pulse velocity measurements are carried out and correlated with established approaches.

Key words: Unconfined compressive strength, density, Protodyakonov strength index, ultrasonic pulse velocity

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CHAPTER 1

Introduction

1.0 Introduction

Society needs material not only to survive but also to enrich it. A nation's strength is directly related to the quantum of valuable minerals available to and consumed by its inhabitants. The valuable minerals are typically sourced from the earth. Mining is the extraction of valuable minerals or other resources from the earth, usually from an ore body or seam. Mining in a wider sense comprises extraction of any non-renewable resource. Mining of stone and metal has been done since pre-historic times. Modern mining methods include a set of process to open a mine and carry out operation in it. It usually involves geological investigation, prospecting, analysing the amount of resource that can be extracted from it, calculate the profit-loss scenario basis, opening of a mine, carrying out extraction processes and finally closing a mine by reclamation. Excavation of earth material these days involve heavy machineries, equipment and tools. The design of those equipment are carried out to match the strength parameter of the rock mass the tool is expected to deal with. The characteristics of rock mass vary widely both at local as well as regional level.

1.1 Background of problem

The design of machineries used in mines have advanced manifold to address the varying nature of rock mass over an area. However the technological advances have not been adequate to eliminate the breakdown of machineries, high rate of wear and tear of cutting tools and the consequential adverse impact on mine economics. One of the major reasons is the inappropriate tool to cut the earth material. Typically the compressive strength of rock is a major design parameter for the selection of cutting tool. The determination of the compressive strength of rock involve an elaborate process often carried out by skilled operation with advanced testing machine in an established laboratory. This exercise is time consuming. Researchers have experimented with many approaches to predict the compressive strength with other parameter which are relatively easy to carry out and determine even at the field. The compressive strength has been correlated with density, Protodyakonov strength index, ultrasonic wave velocities, etc. This investigation is an attempt to determine the different properties of coal and establish correlation among those

1.2 Aim and objectives of the Study

The goal of the investigation is to develop correlation between the different mechanical properties of coal to assist in selecting the right cutting tool. The specific objectives adopted to achieve the goal are following:

a) To critically review the literature to understand different aspects of coal and its behaviour.
b) To determine the mechanical properties of rocks such as unconfined compressive strength, Tensile strength, Protodyakonov strength index &Non-destructive testing of the coal samples.
c) To find correlation between its mechanical properties
d) To evaluate the applicability of a few established equations for the tests values

1.3 Methodology

The objectives mentioned above were accomplished if worked in a plan approach. The first step began with the literature review (Chapter 2). In this regard the books, journals, papers proved to be a rich source of knowledge and were thoroughly studied and learned. This was followed by collection of sample from the local mines. Samples from many sample points were collected and carefully packed hermetically in a vibration proof box and taken to the laboratory for the testing. After the sample collection the samples were prepared for laboratory testing. Results were found out from the experiments and then correlation is done. Conclusions were drawn from the results and analysis. The following flow chart describe details about the methodology

1.3.1 Flowchart

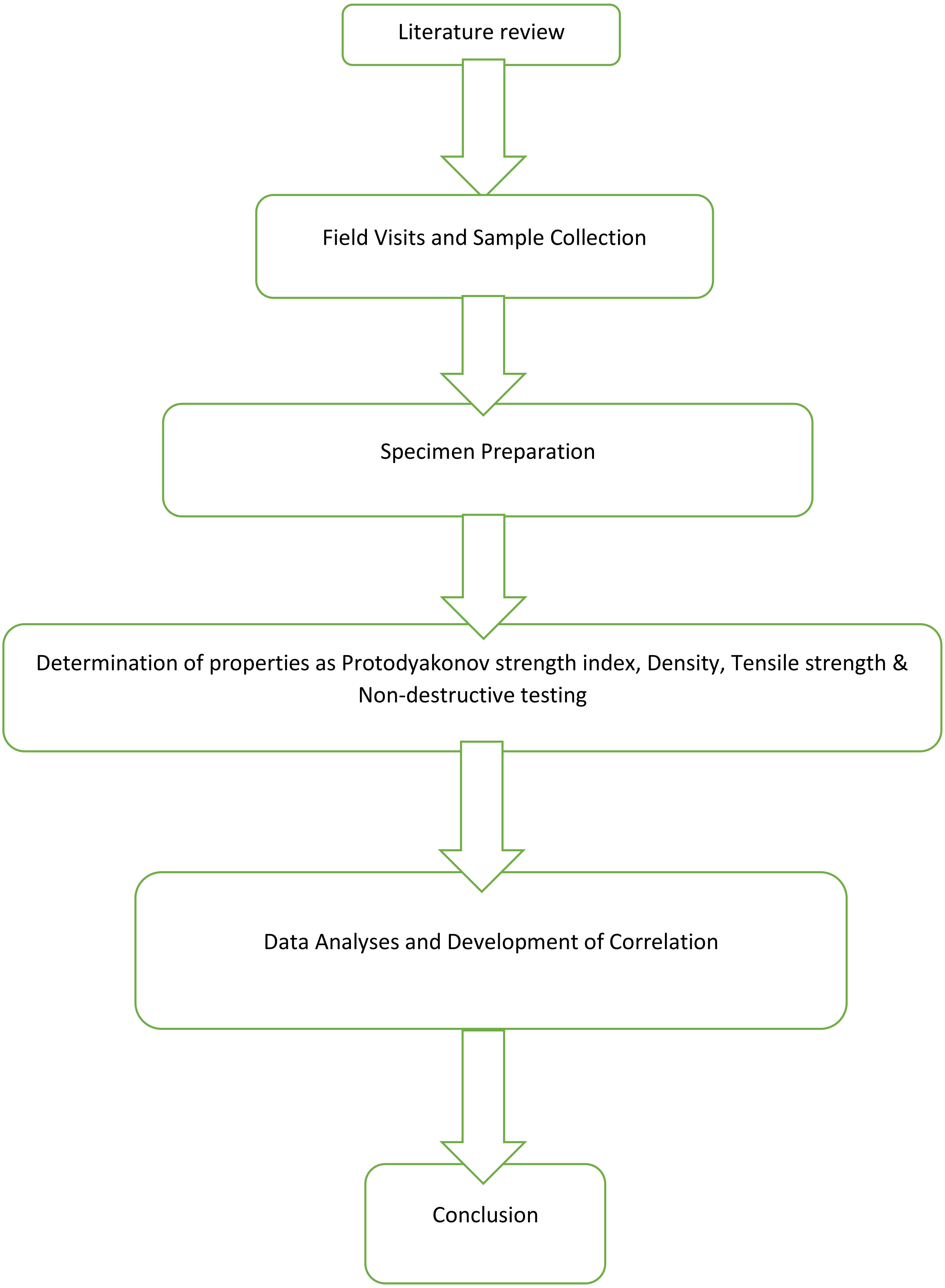

Fig. 1.3 Methodology Flowchart

CHAPTER 2

Literature review

2.0 LITERATURE REVIEW

The aim and specific objectives of the investigation were achieved with the input from an exhaustible and detailed literature review. Pertinent literature on the parameters were reviewed, critically examined and synthesized to understand different aspects of the goal and objectives. The literature were sourced from published journals, books, magazines as well as unpublished reports & dissertation. The following covers the related aspects of the project.

2.1 ROCK

Rock is a naturally occurring solid aggregate of minerals. The Earth's outer solid layer, the lithosphere, is made of rock. In general, rocks are of three types, namely igneous, sedimentary, and metamorphic. The scientific study of rocks is called petrology, and petrology is an essential component of geology. Coal is of sedimentary type.

2.2 MINING

Mining is the extraction of important minerals or other topographical materials from the earth, from a metal body, vein or (coal) seam. This term likewise incorporates the evacuation of soil. Materials recuperated by mining incorporate base metals, valuable metals, iron, uranium, coal, precious stones, limestone, oil shale, rock salt and potash. Mining is obliged to acquire any material that can't be become through rural procedures, or made falsely in a research facility or production line. Mining in a more extensive sense involves extraction of any non-renewable asset (e.g., petroleum, normal gas, or even water).

Mining of coal has been done since a long time ago. Modern mining processes involve prospecting of minerals, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed.

The way of mining procedures makes it a potential negative effect on the earth both amid the digging operations and for a considerable length of time after the mine is shut. This effect has prompted the majority of the world's countries receiving regulations to direct the negative impacts of mining operations. Safety has long been a worry too, however advanced practices have enhanced wellbeing in mines altogether.

.Mining excavation depends a lot on the behaviour of rock mass. The efficiency of equipments also depends on many factors as mechanical, physical and chemical properties. Among the mechanical properties the vital ones are for instance; UCS, Tensile strength index, Density, Impact strength & Dynamic properties.

2.3 Unconfined compressive strength (UCS)

The Uniaxial Compressive Strength (UCS) is an important parameter in rock mechanics that plays a significant role in almost all geotechnical engineering designs to obtain a rough estimation of the soil strength and viable construction techniques. The UCS may give the in-situ stress conditions prevailing in the area which may be an aid in the extraction of Coal Bed Methane (CBM) if the directions of the in-situ stresses are known. The UCS values generally estimated in the laboratory from testing of rock/core samples. The research on the mechanical properties of coal measure rocks specially mudstone/shale have theoretical as well as practical significance on the development of shale gas in coal measures and the control and management of roof/floor rock in mining

The index properties of rocks assume a pivotal part in the arranging and configuration of common and mining excavations, including the stability of dump and rock benches, dependability of underground mining, passages, dams, profound trenches and caves. They are additionally vital for the investigation of rock blasts and bumps in underground mines, for pillar design and the disappointing forecasting ability of rock mass. The determination of these index properties in the research center and in addition in in-situ conditions is dreary and time intensive. It additionally obliges incredible exactness in the planning and testing of tests. There is no such direct technique by which index properties can be acquired, without taking after a relentless and prolonged research center strategy. Accordingly, there is a requirement for a basic procedure for the determination of the list properties of rocks by a roundabout however dependable technique.

2.4 Elastic wave velocities (NDT)

Ultrasonic techniques have been used for many years in geotechnical practice and mining science. They are employed in the field for geophysical investigations and in the laboratory for the determination of the dynamic properties of rocks (Kahraman, 2002). Since these techniques are non-destructive and easy to apply, they are increasingly being used in geotechnical engineering (Sharma and Singh, 2008). Attempts have been made to assess grouting, rock bolt reinforcement and blasting efficiencies in the rock mass by seismic velocity (Knill, 1970; Price et al., 1970; Young et al., 1985). The predictions of rock mass deformation as well as the extent of damage zones developed around underground openings are other applications of seismic techniques.

With the advancement in technology and requirement of pinpoint data, various papers have been published and many articles in journals have paid attention towards the prediction of certain parameters with respect to other i.e. the correlation between various mechanical properties of rocks or minerals.

The following shows some of the pertinent publications related to P-wave velocity, Protodyakonov strength index, Unconfined compressive strength & density.

2.5 Previous Investigations

2.5.1 Khandelwal and Ranjith (2010) tested rock samples from various locations of India mostly of NX size (54 mm diameter) to determine their physico-mechanical properties. Samples used were Quarzite, granite, dolomite, sandstone, limestone, shale, kota stone and marble for measurement of P-wave, Protodyakonov index etc. His data analysis results were as shown below:

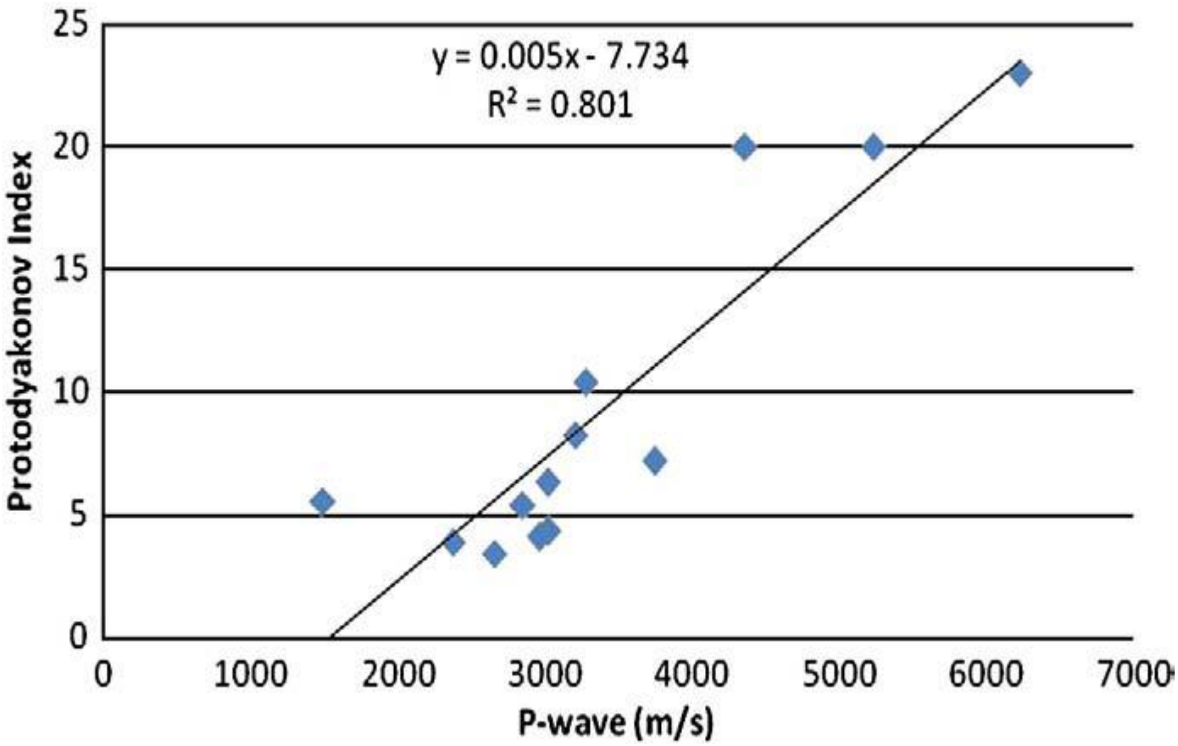

Fig. 2.5.1, Khandelwal and Ranjith correlation

They observed that a good linear relationship exists between the Protodyakonov index and P-wave. They proposed the equations as,

$$Y = 0.005x + 7.734 \qquad \text{................ (2.5.1)}$$

Where, y=Protodyakonov Strength Index,

x =P-wave velocity

Statistical analysis shows little relation by simple regression approach.

2.5.2 According to Soroush and Qutob (2011), correlation between compressional and shear wave velocities shows a linear relationship. After testing 200 core plugs in order to correlate the velocity of P and S waves with some physical and mechanical properties of different rock types including sandstone, siltstone, conglomerate, claystone, granite, andesit, basalt, diabas, quartzite, slate, micro conglomerate, limestone, and marl. They got high regression coefficient (i.e. R^2= 0.9) revealing a strong correlation between the two velocities which enables an estimation of one velocity with the help of another one. The following equation defines this relationship:

$$Vs = 0.456\,Vp + 264.3 \qquad \text{................ (2.5.2.0)}$$

Where, both V_p and V_s are in m/s.

But the equation formulated or summarised does not hold good for all type of rock(e.g. coal).
They also proposed similar linear relationship between parameters such as density and elastic wave velocity & tensile strength and elastic wave velocity.
Relation between density and elastic wave velocity were established as:

$$\rho = -2\ 10^{-8}(V_p)^2+0.0002\ V_p+1.93, \text{ and} \qquad \text{................ (2.5.2.1)}$$

$$\rho = -6\ 10^{-8}(V_s)^2 +0.0004\ V_s +1.94$$

With simple statistical analysis shows a rather satisfactory result for both the established correlation.
Relation between tensile strength and elastic wave velocities formulated as:

$$T = 0.348e^{0.0004Vp}, \text{ and}$$

$$T = 0.277e^{0.0008Vs} \qquad \text{................ (2.5.2.2)}$$

Results obtained after analysis mostly violates with the actual laboratory data by some distance.

2.5.3 Ramouni et al (2013) also established relation between P-wave velocity and density.Materials used in his study were sedimentary rocks i.e. calcarenite and as much as six rock samples were cored in size of 7*7*7 $cm^3$to determine the physical parameters. He found outa linear relation between density and P-wave velocity.

The equation established by regression analysis as:

$$V_p = 1.2466\rho + 1.6065 \quad \text{.................. (2.5.3)}$$

Where, ρ = Density of rock

But according to data obtained during lab testing are not along with the predicted data and therefore does not holds good for all rock types.

2.5.4 Chaterjee et al (2013) approached similar method of regression analysis to find out correlation between density and unconfined compressive strength. They used a total of 84 coal and non-coal samples to determine the unconfined compressive strength, density and few other parameters. The developed relation is a power relation between the two aforementioned parameters and equated as:

$$Y=0.004(x)^{2.40}, \quad \text{.................. (2.5.4)}$$

Where x & y being density and UCS respectively.

However, the predicted data vary a little with coal samples from other regions.

2.5.5 Similar efforts were put in by Mahmoud (2013) by experimenting 30 sandstone rock specimens taken at different depths below ground surface to correlate between density, UCS and other parameters.

He developed a linear relation equated as:

$$UCS=371.3(\rho)-535.6 \quad \text{.................. (2.5.5)}$$

Where, ρ=Density

And stated that studied parameter such as dry density is considered to have a small effect on the unconfined compressive strength (Qu), so that it can be neglected.

CHAPTER 3

Field visits and Sample Collection

3.0 FIELD VISITS AND SAMPLE COLLECTION

The objective of the project were to determine a few properties of coal and develop correlation among those as well as evaluate the applicability of established equations and compare those with the developed ones. It involves testing of a large number of samples. The samples were collected from different locations as Talcher, IB valley and Jharkhand area.

The samples have been taken from:

- ✓ Talcher area
- ✓ IB valley area
- ✓ Jharkhand area

3.1 Geology:

3.1.1 Talcher:

As indicated by Geological Survey of India, the Talcher Coalfield has stores of 38.65 billion tons, the highest in India. Talcher Coalfield covers a territory of 500 square kilometers (190 sq mi). The coal is of lower quality containing just around 35 percent of carbon, 40 percent of volatile matter and 25 percent of ash content. Starting 2011, about one hundred thousand tons of coal is despatched day by day to power stations in Odisha, Tamil Nadu, Andhra Pradesh, West Bengal and different parts of India.

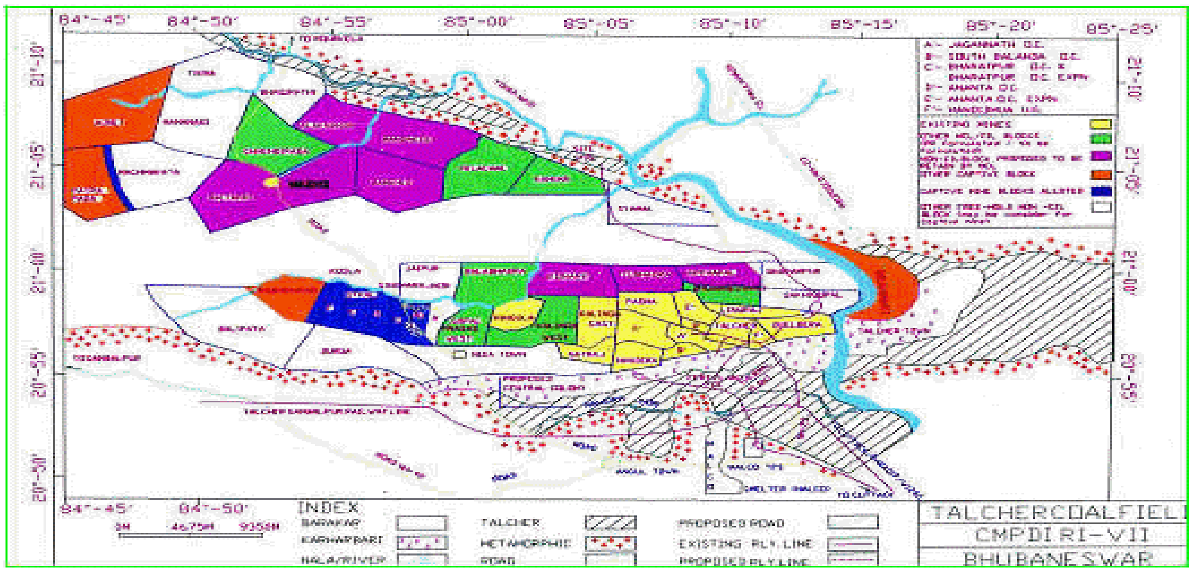

Fig. 3.0.1, Map of Talcher coalfields

3.1.2 IB Valley

This Coalfield is a piece of vast synclinal Gondowna Basin of Raigarh-Hingir and Chhattisgarh Coalfields (Mahanadi Valley) and structures its South Eastern generally part.

Coal probability of this fields was researched as early as 1871-75 by Mr. V. Ball of GSI. A few works were likewise done by Mr. W. King amid 1884-86. Amid 1900-01 exposures of different seams were discovered while developing extension over IB River on the Bombay Howrah Railway line. Further work was embraced by Geological Survey of India. Amid 1977 CMPDIL depended the Directorate of Mining & Geology (Govt. of Orissa) for subtle element investigation. Barakar and Karharbari measures are the major coal bearing formations.

Barakar formation contains as many as twenty carbonaceous horizons with coal grade ranging from E to G. These skylines have been clubbed and five seams have been distinguished in the territory, specifically Belpahar, Parkhani, Lajkura, Rampur and IB Seams. Parkhani seam is sporadic in quality and thickness. It is by and large not found as mineable. Belpahar seam happens in the profound side of Lakhanpur OCP and mining operation in this seam is not anticipated in not so distant future.

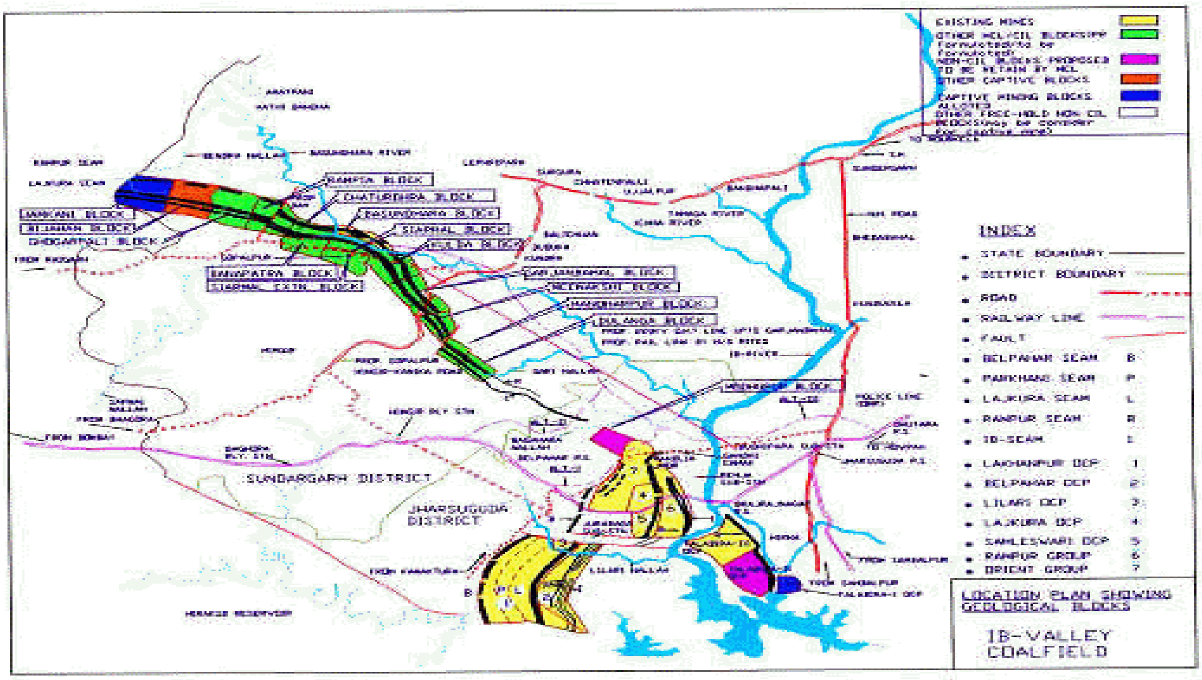

Fig. 3.0.1, Map of IB Valley

3.1.3 Jharkhand

Around 33% of the evaluated coal stores are disseminated in the coalfields of Jharkhand and Bihar. Critical coalfields of this state are Jharia, Bokaro, Giridih, Karanpura, Ramgarh, Daltonganj, Auranga and Hutar. A part of the Raniganj coalfield of West Bengal falls in this state. Coalfields of the Damodar valley are the boss wellspring of metallurgical coal in the nation and the vast majority of the iron and steel plants get coking coal from these fields. Relative importance has declined definitely from 47 percent of aggregate coal production of the nation in 1970 to 26 percent in 1998-99. Therefore, it now second place among the coal producing states**.**

3.2 Sample Collection Locations:

Fig. 3.2.1 Sample collection site

3.3 Sample preparation

The dimensional, shape, and surface resilience of coal core samples are critical for deciding coal properties of in specimens. This is particularly valid for delicate rocks. Subsequently different tests are completed to focus the quality parameters of the stones and break down its deformity attributes.

The measure of dampness of the sample at the time of the planning of test can have a noteworthy impact upon the quality and deformity attributes of the coal. Great practice for the most part manages that research facility tests be made upon samples illustrative of in-situ conditions. So that the real conditions and moisture content in the sample stays in place amid research facility testing. Still, there may be explanations behind testing examples at other dampness substance, from immersion to dry. So its ideal to know the moisture conditions so it can be taken care of appropriately. Abundance dampness will influence the grip of resistance strain gages, if utilized, and the precision of their execution. Adhesives used to bond the soft rock to steel end pieces of the apparatus in the direct tension test will also be affected adversely by excess moisture in the sample.

Specifying procedures for laboratory rock test specimen preparation of rock core from drill core and block samples for strength and deformation testing and for determining the conformance of the test specimen dimensions with tolerances established.

Table 3.3: Sample size required for different tests

TESTS	SAMPLE SIZE
UCS	L/D = 2-2.5
PROTODYAKONOV STRENGTH INDEX	(-)4.75mm to (+)3.35mm 50 grams of coal (each test)
TENSILE TEST	L/D = 0.5
NON-DESTRUCTIVE TESTING	L/D = 1.5-2.5

Rock cores are the sample of record which gives the actual existing conditions of the field and at particular borehole location. The samples are expected to yield significant indications about the geological, physical, chemical and engineering nature of the subsurface for use in the design and construction of an engineered structure. The core samples need to be preserved using specific procedures for a stipulated time so that it can reflect the actual conditions of the field. The period of storage depends upon the nature and significance of the engineered structure and the type of laboratory testing to be carried out.

Fig. 3.3 Coring Machine

Rock cores always need to be handled and preserved such that their properties are not altered in any way due to mechanical damage or changes in ambient conditions of moisture and temperature or other environmental factors.

- This practice covers the guidelines, requirements, and procedures for core drilling, coring, and sampling of rock for the purposes of site investigation as per ASTM D4543 (American Society for Testing and Materials)

- The coring of the borehole could be vertical, horizontal, or angled.

- This practice applies to core drilling in hard and as well as soft rock.

- The values that are given in inch-pound are taken as standards while the values which are mathematically converted to SI units are not to be taken as standard.

- This practice does not support to comprehensively address all of the methods and the issues associated with coring and sampling of rock.

- Persons with proper knowledge and skills of using the equipment to perfect use should be involved in carrying out this process.

3.4 Storage

- The samples gathered from the site were kept at a different spot.
- These tests are either kept for in-situ testing or lab testing.
- The tests for in-situ testing are straightforwardly utilized at the site.
- Some tests which will be taken for lab testing is kept in plastic sacks.
- Plastic packs are utilized to shield it from dampness and other gases.

3.5 Transportation of Samples

- Transportation of samples is usually done by railways to minimize the vibration.
- Samples which are collected in plastic bags which stop interaction of the samples with the external atmosphere are kept in hardboard boxes.
- The samples were also provided with shock absorbing materials inside the boxes such as thermocol to prevent any damage during transportation.
- Hardboard boxes are usually preferred during the transporting of the rock samples to protect it from sunlight.
- Heat of the sun during transportation of the samples can cause fire in the coal samples if exposed directly. Hence hardboard boxes protect the samples efficiently.
- Hardboard boxes also protect them from rainfall and reduce the chances of faulty samples in the laboratory testing.
- Hardboard boxes along with the plastic bags preserve the true nature of the samples from the site to the laboratory.

3.6 Testing

The most vital and essential scope in rock mechanics is measuring and determination of rock properties and behaviour by using the recommended testing methods, procedures, and specifications. These include the engineering characteristics of rock such as its strength, mode of deformation, mode of failure, and modulus of elasticity, sonic velocity index, tensile strength etc.

3.7 Determination of properties of coal

The properties of the samples to be tested in the laboratory are

1. Protodyakonov strength index
2. Density
3. Non-destructive testing
4. Tensile Strength

3.7.1 Protodyakonov strength index:

Protodyakonov (1962) proposed the assessment of the mechanical properties of rocks by method for relative strength coefficient, called the Protodyakonov Index (f). The Protodyakonov Rock Strength Scale was initially formulated as a record identifying with compressive quality, and was characterized as the strength in kgf/cm^2 partitioned by 100. As a determination of this record requires broad research facility offices, a handle strategy was contrived, utilizing a mortar and falling weight to break the stone and a volumemeter to focus the fines underneath 0.5 mm. An observational relationship was utilized to relate the two routines. The Protodyakonov Index can be dead set in the lab by the accompanying experimental equation:

$$f = (20n)/h$$

Where, n = number of impacts of the drop weight on each sample

h= volumeter height.

3.7.2 Density:

Density is defined as mass per unit volume

At first total volume of core samples are determined from the following expression,

$$V_d = \pi r^2 h$$

Where V_t = total volume of core sample,

π = 3.141 (constant),

r = radius of core sample, and

h = length of core sample.

3.7.3 Non-destructive testing:

The techniques available for characterization of materials can be categorized in two broad classes, destructive and Non-Destructive Techniques. The destructive techniques cause certain variation in physical shape of and material properties, in some cases it damages the materials. Thus there will be degradation of the strength of the material is being evaluated. In Non-Destructive evaluation technique there is no physical damage while characterization of the material.

The common NDT Techniques are as listed below:

A. Dye penetrant inspection

B. Magnetic Particle Testing

C. Ultrasonic Testing

D. Eddy Current Testing

E. Radiographic Testing

A. Dye penetrant inspection

It has a wide range of application due to its low-cost inspection method which is used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity leaks in new products, and fatigue cracks on in-service components.

B. Magnetic Particle Testing

This method is most suited for the detection of surface and near surface discontinuities in magnetic material, mainly ferric steel and iron. The principle is to generate magnetic flux in the article to be examined, with the flux lines running along the surface at right angles to the suspected defect. Where the flux lines approach any fault they will stay out in to the air at the mouth of the crack. The technique not only detects those defects which are not normally visible to the unaided eye, but also renders easily visible those defects which would otherwise require close scrutiny of the surface.

C. Ultrasonic Testing

In ultrasonic testing (UT), short ultrasonic pulse waves with focus frequencies extending from 0.1-15 MHz and at times up to 50 MHz are dispatched into materials to identify inward imperfections or to characterize materials. A typical illustration is ultrasonic thickness estimation which tests the thickness of the test article, for instance, to monitor pipe work erosion. Ultrasonic testing is frequently performed on steel and different metals and combinations, however it can likewise be utilized on solid, wood and composites, though with less determination. It is a type of non-ruinous testing utilized as a part of numerous commercial enterprises including aviation, car and other transportation divisions.

D. Eddy Current Testing

Eddy current testing uses electromagnetic incitation to recognize flaws in conductive materials. Eddy current can be made in any electrically driving material that is subjected to a pivoting alluring field. The substituting appealing field is consistently made by passing a rotating current through a circle. The loop can have various shapes and can some place around 10 and 500 turns of wire. The degree of the eddy current made in the thing is liable to conductivity, permeability and the set up geometry. Exactly when a break, for example, happens in the thing surface the eddy current must travel more remote around the part and this is perceived by the impedance change.

E. Radiographic Testing

This procedure is suitable for the revelation of inward surrenders in ferrous and nonferrous metals and diverse materials. X-beams, produced electrically, and Gamma beams transmitted from radio-dynamic isotopes, are invading radiation which is differentially devoured by the material through which it passes; the more unmistakable the thickness, the more foremost the ingestion. Material with inside voids is attempted by putting the subject between the wellspring of radiation and the film. The voids show as darkened reaches, where more radiation has arrived at the film, on an unmistakable establishment.

CHAPTER 4

Laboratory Experimentation

4.0 Laboratory experiments to determination various engineering parameters of rock as

1. Protodyakonov strength index,
2. Density,
3. Tensile strength &
4. Non-destructive testing of the samples collected.

4.1 Unconfined Compressive Strength (UCS):

One of the important parameters that determine rock strength and hardness is compressive strength as is simulates the condition of the rock under pressure and simultaneously predicts is behaviour. The samples were tested as per ASTM D2166/D2166M standards.

- The cylindrical sample is placed at the center of the loading platens.
- The upper platen is adjusted carefully so that the platen just makes contact with the cylindrical sample.
- The gauge for measuring deformation is made zero or the initial reading is noted. The loading rate of the compressive load was 0.5 to 1.0 MPa/sec.
- The load, axial deformation and longitudinal deformation are noted at sufficient intervals.
- The load is increased steadily till the failure occurs in the sample. The failure load is noted and divided with cross sectional area of the sample to get the unconfined strength value of the representative sample.

Fig.4.0 Coal Sample under Compressive loading

4.2 Protodyakonov Impact Strength Test

Protodyakonov Impact Strength Index (PSI) is a method for describing coal quality, which has gigantic plausibility for viable execution in coal cutting and boring. It additionally gives a thought regarding the uniaxial compressive strength of the rocks.

4.2.1 Method

Impact strength index test is first discovered by Protodyakonov to put forward an idea about the Rock's strength properties, cuttability and brittleness, then is improved by Evans & Pomeroy (1966)

- This technique is based upon the crushability of rock under standard experimental condition.
- This test was performed by the use of a vertical cylinder apparatus which is 30-48 cm in height and has a steel plunger.
- 100 gm of sample were taken of size -4.75 mm to + 3.35 mm is taken in the cylinder.
- 50 gm of sample were taken if the sample is coal.
- A plunger was dropped from a height of 65 cm into the cylinder in which the sample is kept.

- The weight of the plunger taken was around 2.4 kg.
- The plunger was dropped 20 times in the cylinder if the sample was rock and 15 times if the sample was coal.
- The crushed sample was collected and was sieved through 0.5 mm sieve.
- The -0.5 mm sample were collected and filled in the volumeter.
- The height “h” in the volumeter was measured.
- Protodyakonov impact strength index was found out by using the following formulae

P.S.I = (20 x n)/h

Where, P.S.I = Protodyakonov strength index

n = no of blows

h = height in the volumeter

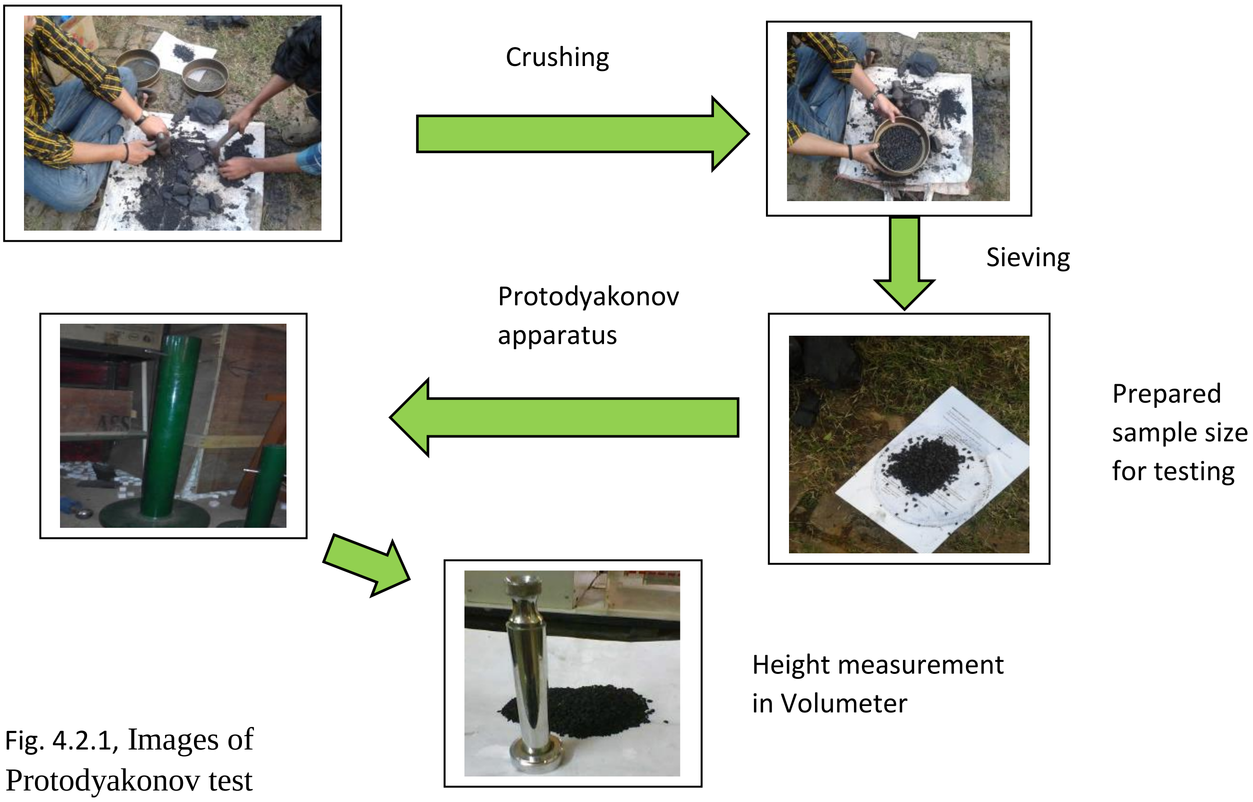

Fig. 4.2.1, Images of Protodyakonov test

4.3 Non-destructive testing

Since rocks are non-homogenous, elasto-plastic material, it has dependably been hard to anticipate the conduct of rock under any stress stacked environment. Now and then it gets to be exorbitant to make the mining environment clear, so some viable routines have been attempting to grow over years. One of them is acoustic strategies taking into account the hypothesis of versatility. The versatile properties of substances are portrayed by the strain module or constants that determine the relationship in the middle of stress and strain. The strains in a body are deformations, which deliver restoring powers contradicted to the stress. Tensile and compressive stresses offer ascent to longitudinal and volume strains, which are measured as unit changes long and volume underweight. Shear strains are measured by disfigurement points. It is normally accepted that the strains are little and reversible, that is, a body continues its unique shape and size when the stresses are alleviated. If the stress in an elastic medium is released suddenly, the condition of strain propagates within the medium as an elastic wave.

Fig. 4.2 Image of NDT testing setup

The rule of the ultrasonic testing technique is to make waves at a point and focus on the time of landing in various different points for the vitality that is going inside distinctive rock masses. The speed of ultrasonic heartbeats going in a strong material relies on upon the thickness and versatile properties of that material. The nature of some stone masses is here and there identified with their flexible firmness and rock mass structure, such that the estimation of ultrasonic pulse speed in these materials can regularly be utilized to show their quality, and also to point their versatile properties. Voyaging speeds of ultrasonic pulses are high in homogenous rock masses with high mechanical properties (UCS, elasticity, attachment, inner erosion edge), which can be utilized as distinguishing the nature and quality of any stone structure. A few strategies had been created to quantify rock diggability, stress conveyance close to a mine opening, seat impacting effectiveness because of basic distinguishing proof of rock masses by contrasting the ultrasonic pulse voyaging speeds in a reference test with genuine in-situ estimations.;

$$\text{Young's Modulus (E)} = \rho * V_s^2 * [8V_p^2 - 4Vs^2] / [V_p^2 - V_s^2]$$

$$\text{Bulk Modulus (K)} = \rho * [8V_p^2 - 4Vs^2] / 3$$

$$\text{Shear Modulus (G)} = \rho * V_s^2$$

$$\text{Poisson's Ratio} = [V_p^2 - 2Vs^2] / [2*(V_p^2 - V_s^2)]$$

Where, V_p = P-wave velocity,

V_s = S-wave velocity, and

ρ = Density

4.4 Density (ρ)

The density of a material is defined as its mass per unit volume. The symbol of density is ρ (the Greek letter rho).

Mathematically:

$$\rho = m/V,$$

Where, ρ (rho) is the density,

m is the mass,

V is the volume.

Different materials usually have different densities, so density is an important concept regarding buoyancy, packaging and metal purity.

In some cases density is expressed as the dimensionless quantities specific gravity (SG) or relative density (RD), in which case it is expressed in multiples of the density of some other standard material, usually water or air/gas.

Specific gravity (SG) - Relative density, or specific gravity, is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference material. Specific gravity means relative density with respect to water.

On the off chance that a substance's relative thickness is under one then it is less thick than the reference; if more prominent than one then it is denser than the reference. Again if the relative thickness is precisely one then the densities are square with; that is, measure up to volumes of the two substances have the same mass. In the event that the reference material is water then a substance with a relative thickness (or particular gravity) under one will skim in water.
Relative density (RD) or specific gravity (SG) is a dimensionless quantity, as it is the ratio of either densities or weights

$$\text{Relative Density} = \rho_{\text{substance}} / \rho_{\text{reference}}$$

Where, RD is relative density,

$\rho_{\text{substance}}$ = density of the substance being measured, and

$\rho_{\text{reference}}$ = density of the reference. (By convention ρ, the Greek letter rho, denotes density.)

CHAPTER 5

Result and Analysis

5.0 Introduction:

The aim or objective have been achieved by step by step process as site visits, sample collection, sample preparation , laboratory tests and observation so that a major parameter can be predicted using some simple and less time consuming tests. The specific objective is determination of strengths. The investigation was carried out with the understanding of many materials. A thorough and exhaustive literature review was carried out to understand different aspects of excavation efficiency, influencing parameters and operation. Those resources were sourced from available literature, the literature covered published articles or journals as well as unpublished reports and thesis. Samples were collected and tested. The different mechanical parameters of coal such as Protodyakonov strength index, density, UCS, and ultrasonic velocity measurement, and their mutual relations were found out and compared with the developed or established approaches. Following are the results and interpretation of data.

5.1 Tests and results:

On an average three to four samples were tested for each parameter and the average values were reported here.

5.1.1 Unconfined compressive strength (UCS):

The compressive strength values of coal samples varied between 9.7228 MPa and 28.5 MPa as below.

Table 5.1.1: Unconfined Compressive Strength Test Results

Sample Name	Average UCS (MPa)	E (MPa)	μ (Poisson's Ratio)
A	89.45	496.7513	0.0445
B	92.92	1138.406	0.3666
C	105.91	1321.886	0.9117
D	95.75	1134.991	0.678
E	120.74	1264.963	0.3438
F	98.55	189.0033	0.1178
Mean	16.6698	924.3335	0.4104
Std. Deviation	7.1989	466.4368	0.3313

The average value obtained was 16.67 MPa with standard deviation of 7.199. The specimen were coal samples collected from open cast operations. These values varies because of weathering and other conditions.

5.1.2 Protodyakonov Strength index

After testing around four samples, the average value of the Protodyakonov strength index were noted which varied between 89.45 and 120.74.

Table 5.1.2: Protodyakonov Strength Index Test Results

Sample Name	Avg. PSI
A	89.45
B	92.92
C	105.91
D	95.75
E	120.74
F	98.55
Mean	100.5533
Standard Deviation	25.3949

The mean Protodyakonov strength index found to be 100.5533 with the standard deviation of 25.3949. The variation of the data were largely due various geological conditions.

5.1.3 Non-destructive testing

Table 5.1.3: Elastic Wave Velocity Test Results

Sample name	Vp (m/s)	Vs (m/s)	E	µ
A	1519	739	2302	0.34
B	1572	778	2577	0.34
C	1587	669	2058	0.39
D	1539	596	1397	0.41
E	1567	676	2013	0.39
F	1559	610	1615	0.41
Mean	1557.167	678	1993.67	0.38
Standard deviation	54.738	158.6	969.154	0.072

The average p-wave and s-wave velocity were found to be within the range of 1519 m/s and 1587 m/s and 596 m/s and 778 m/s respectively. The mean and standard deviation for p-wave was found to be 1557.167 m/s and 54.738 m/s respectively, similarly for s-wave the values were 678 m/s and 158.6 m/s.

5.1.4 Density

Table 5.1.4: Density Test Results

Sample name	Average density (Kg/m^3)
A	1570
B	1590
C	1650
D	1390
E	1590
F	1540
Mean	1555
Standard deviation	197.864

The density values of the samples tested ranged between 1390 (Kg/m^3) and 1590 (Kg/m^3) with mean and standard deviation of 1555 and 197.864 (Kg/m^3) respectively.

5.1.5 Tensile Strength

Table 5.1.5: Tensile strength Test Results

Sample name	Average бt (MPa)
A	1.828
B	2.113
C	2.061
D	2.503
E	1.577
F	2.087
Mean	2.0282
Standard deviation	0.6934

The tensile strength values of the samples tested ranged between 1.577 (MPa) and 2.113 (MPa) having mean and standard deviation of 2.0282 and 0.6934 (MPa) respectively.

5.2.0 Development of correlation:

5.2.1 Correlation between UCS and density:

The different test results were used to evaluate their mutual dependency for the given range. It was observed that as the density increases the UCS values also increase.

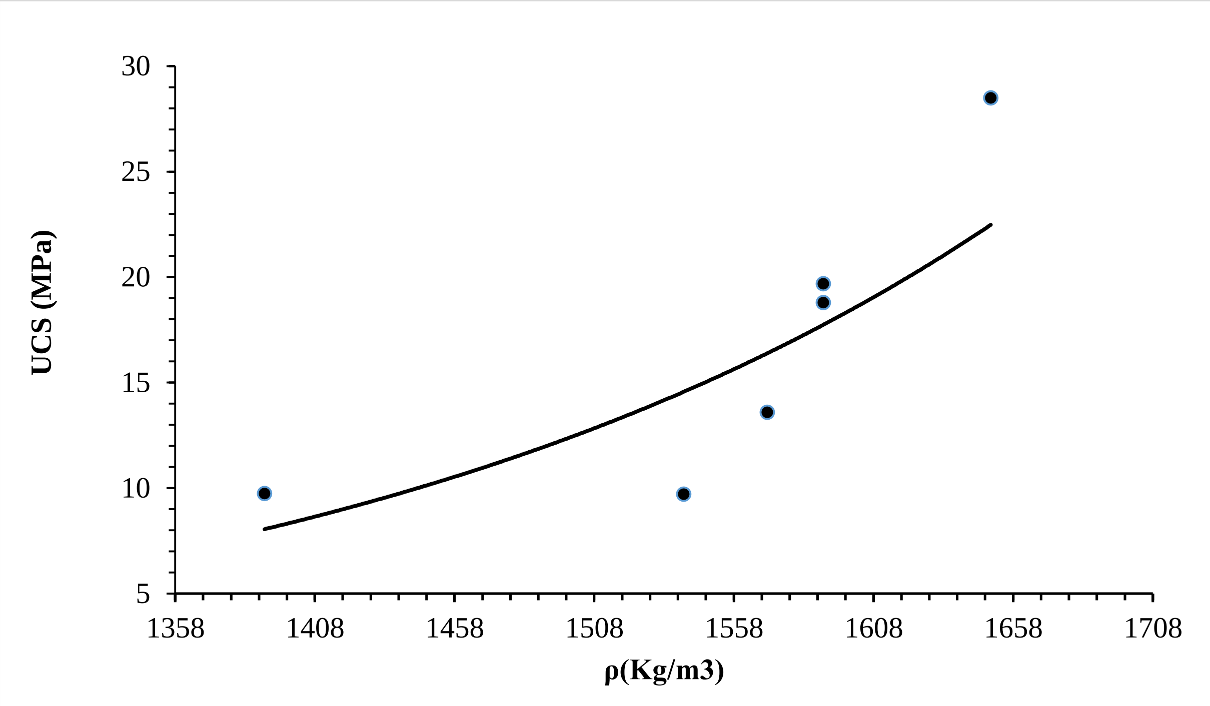

Fig. 5.2.1 Density vs UCS of Coal

The exponential regression analysis produced the following equation (fig.5.2.1) as:

$$\boxed{Y=0.0334e^{0.0039x}} \quad \text{.................. (5.2.1)}$$

Where Y=UCS (MPa),

X=Density (Kg/m3)

The correlation coefficient (R) was found as 0.816.

5.2.2 Correlation between UCS and Protodyakonov strength index

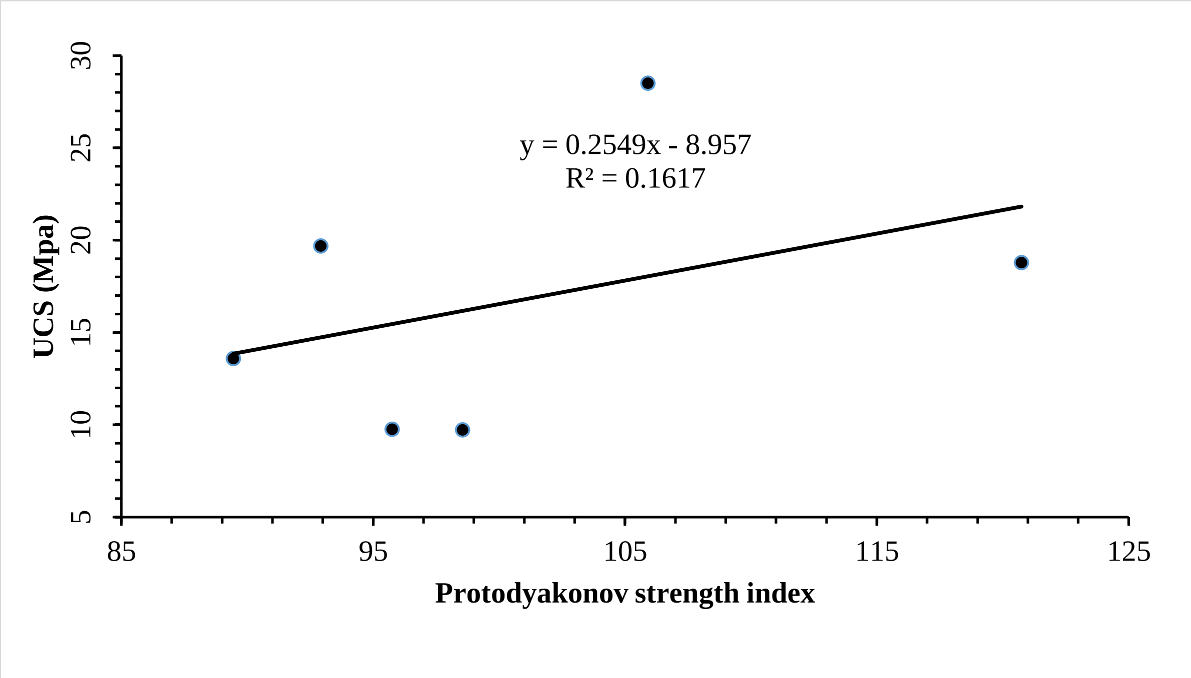

Fig. 5.2.2 Protodyakonov Strength Index vs UCS

The linear regression analysis produced the following equation (fig.5.2.2) as:

$$\boxed{Y=0.2549x-8.957} \qquad \text{..................} \ (5.2.2)$$

Where Y=UCS (MPa),

X=Protodyakonov strength index

The correlation coefficient (R) was found to be 0.402

5.2.3 Correlation between P-wave velocity and Density:

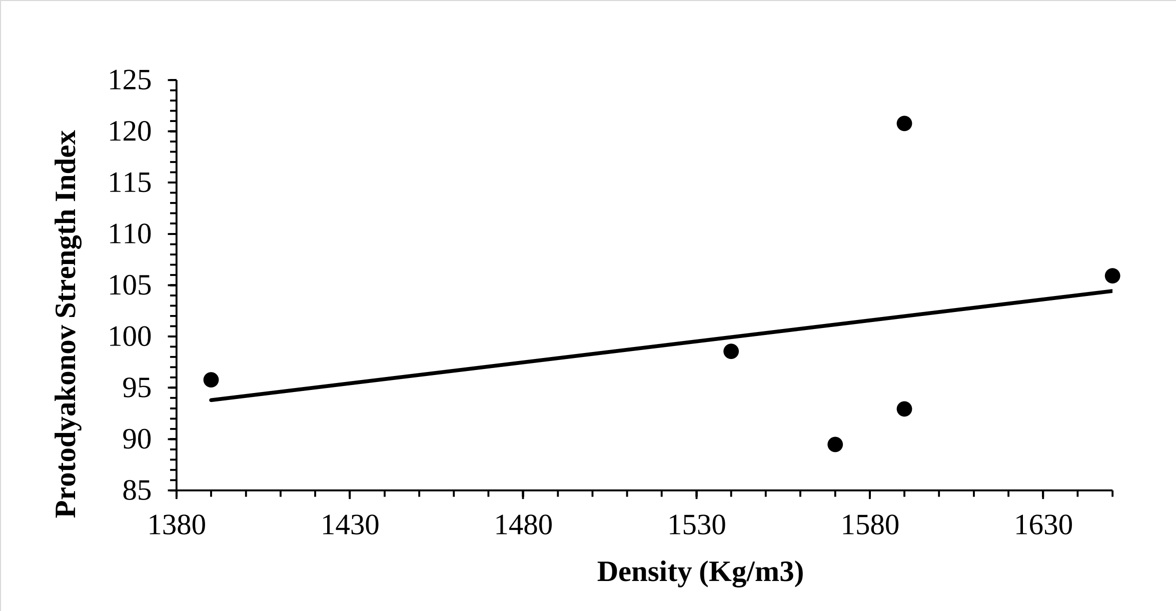

Fig. 5.2.3 Density vs Protodyakonov Strength Index

The linear regression analysis produced the following equation (Fig.5.2.3) as:

$$\boxed{Y=0.041x+36.832} \qquad \text{.................. (5.2.3)}$$

Where, Y=Protodyakonov strength index,

x=Density (Kg/m3)

The correlation coefficient (R) was found to be 0.319.

5.2.4 Correlation between density and S-wave velocity:

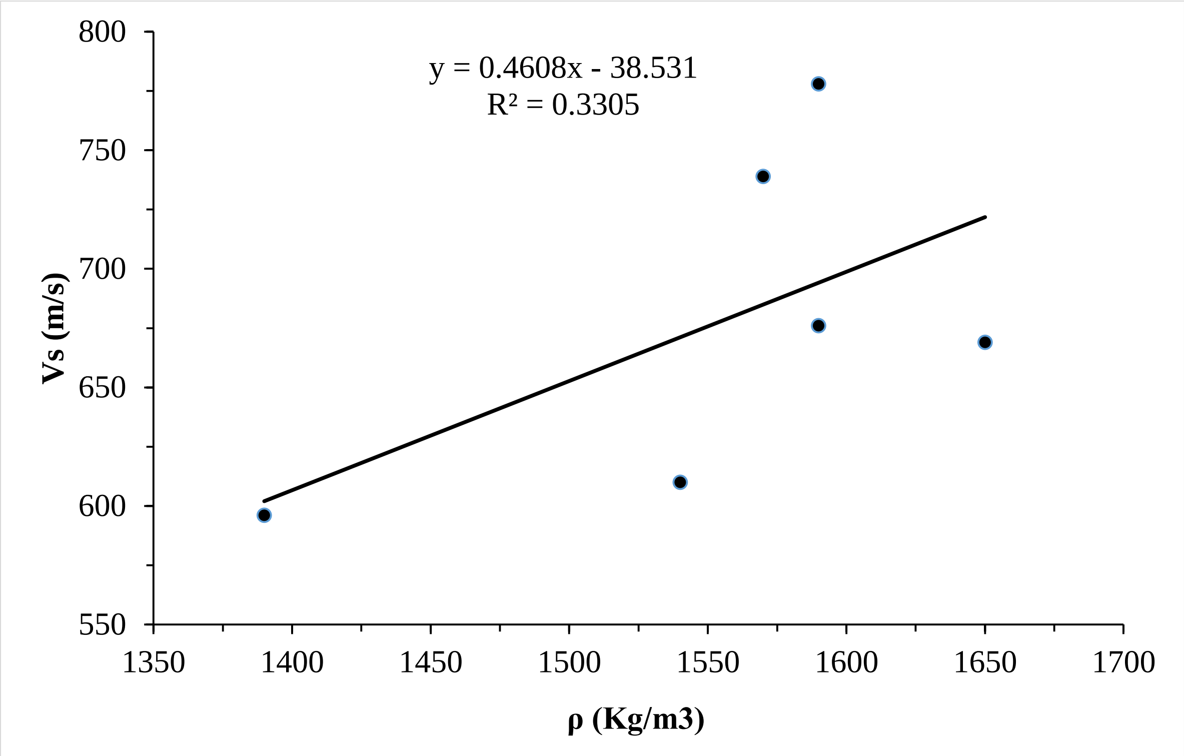

Fig. 5.2.4 Density vs S-wave velocity

The linear regression analysis produced the following equation (fig.5.2.4) as:

$$\boxed{Y=0.4608x-38.531} \quad \text{..................} (5.2.4)$$

Where, y=S-wave velocity,

X=Density (Kg/m3)

The correlation coefficient (R) was found to be 0.575

5.2.5 Correlation between Tensile strength and P-wave velocity:

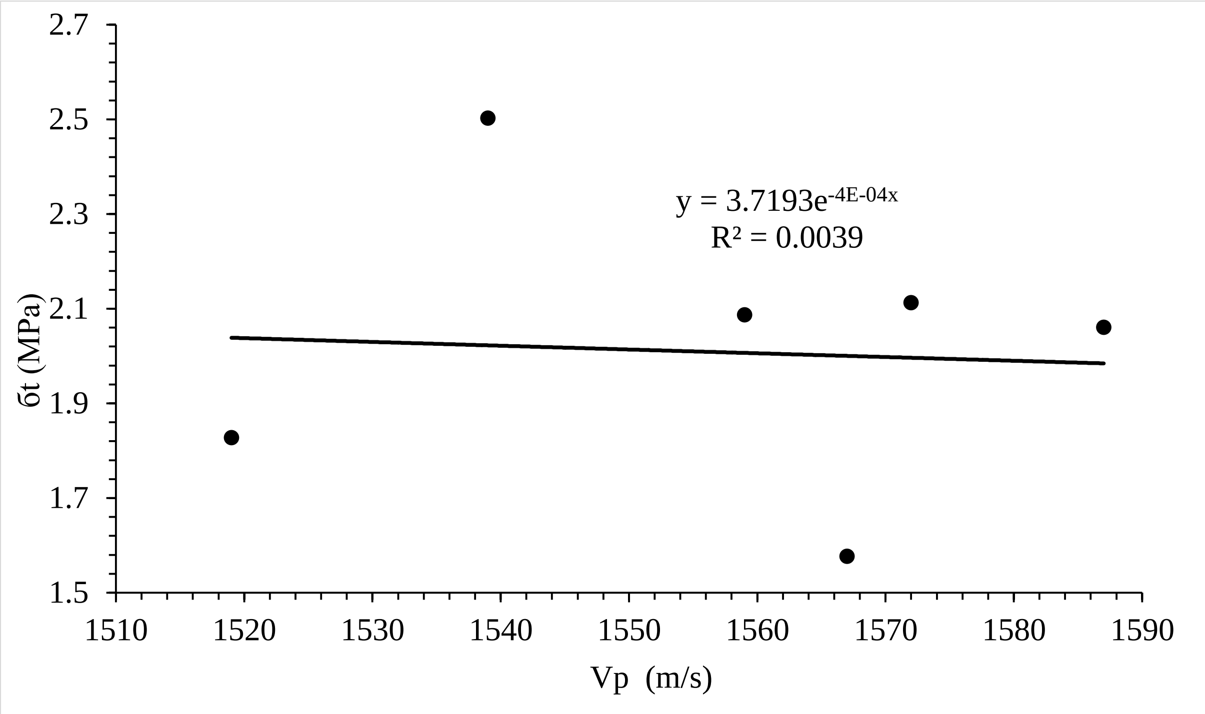

Fig. 5.2.5 P-Wave Velocity vs Tensile Strength

The exponential regression analysis produced the following equation (fig.5.2.5) as:

$$\boxed{Y=3.7193e^{-4E-04x}} \quad \text{.................. (5.2.5)}$$

Where, y=Tensile strength (MPa)

x=P-wave velocity (m/s)

The correlation coefficient (R) was found to be 0.0624

5.2.6 Correlation between Tensile strength and S-wave velocity:

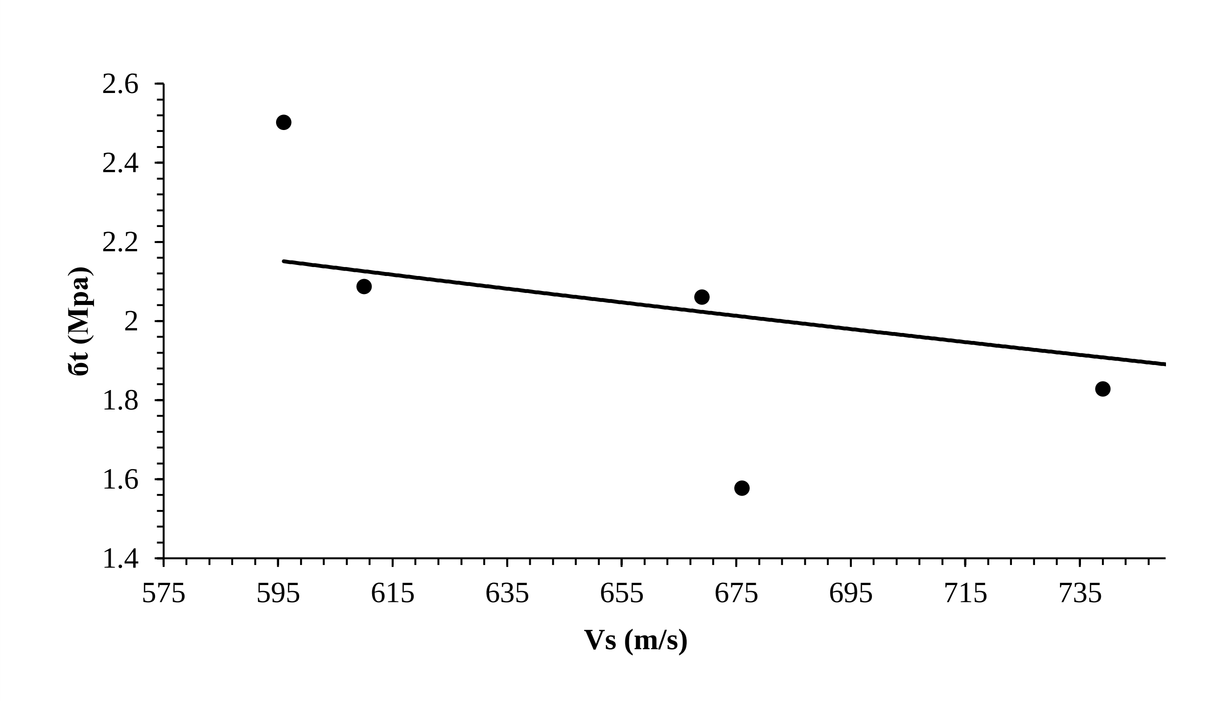

Fig. 5.2.6 S-Wave Velocity vs Tensile Strength

The exponential regression analysis produced the following equation (fig.6) as:

$$\boxed{y = 3.5441e^{-8E-04x}} \qquad \text{.................... (5.2.6)}$$

Where, y=Tensile strength (MPa)

x=S-wave velocity (m/s)

The correlation coefficient (R) was found to be 0.383.

5.3.0 Analysis of experimental results with respect to some predicted values:

5.3.1 There exists a number of equations suggested by different researches discussed elsewhere (section 2.5.1). The applicability of those equations were evaluated with the test data. The equation proposed by Khandelwal and Ranjith (2010) was:

$$y = 0.005x - 7.734$$

Where y=Protodyakonov strength index,

x=P-wave velocity (m/s)

The predicted Protodyakonov strength index values from the P-wave elastic velocity was plotted against the measured values (fig.5.3.1). There exists a trend of predicted Protodyakonov strength index that compare favourably with the actual values though the magnitude varies. The relation obtained as:

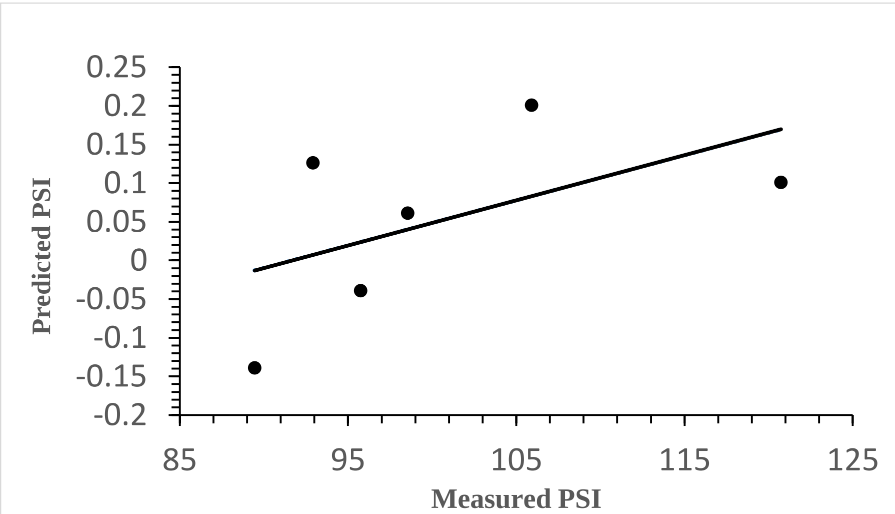

Fig.5.3.1 Protodyakonov Strength Index analysis

Predicted Protodyakonov strength index= 0.0058x - 0.5348 .... (5.3.1)

Where x= measured Protodyakonov Strength Index (MPa)

With R=0.541

However the relation does not agree when the index values are low. The equation suggested by Khandelwal and Ranjith is acceptable for high Protodyakonov strength index values.

5.3.2 Chaterjee et al approached similar method of regression analysis (section 2.5.4) to find out correlation between density and unconfined compressive strength. The equation proposed as:

Y=0.004(x) E-2.40,

Where, y= UCS (MPa)

x= Density (Kg/m3)

The predicted UCS values from the density was plotted against the measured values (fig.5.3.2). There exists a trend of predicted UCS that compare favourably with the actual values though the magnitude varies. The relation obtained as:

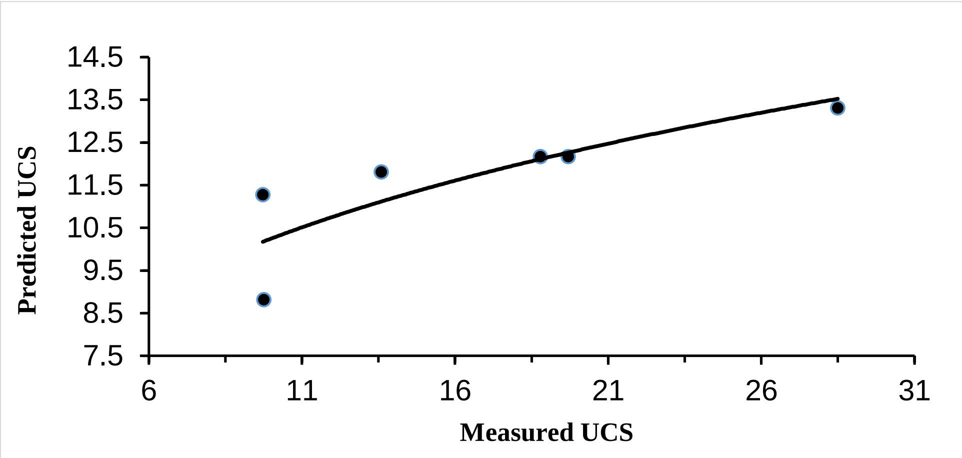

Fig. 5.3.2

UCS Analysis

$$\text{Predicted UCS} = 5.5719x^{0.2647} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.3.2)$$

Where x= measured UCS (MPa)

As the correlation coefficient suggests the predicted equation holds a good relation with the predicted and measured data.

5.3.3 Mahmoud also approached a linear regression analysis (section 2.5.4) to find out correlation between density and unconfined compressive strength. The equation proposed as:

$$y = 0.3517x - 18.035,$$

Where y= UCS (MPa)

x= Density (Kg/m3)

The predicted UCS values from the density was plotted against the measured values (fig.5.3.3). There exists a trend of predicted UCS that compare favourably with the actual values though the magnitude varies. The relation obtained as:

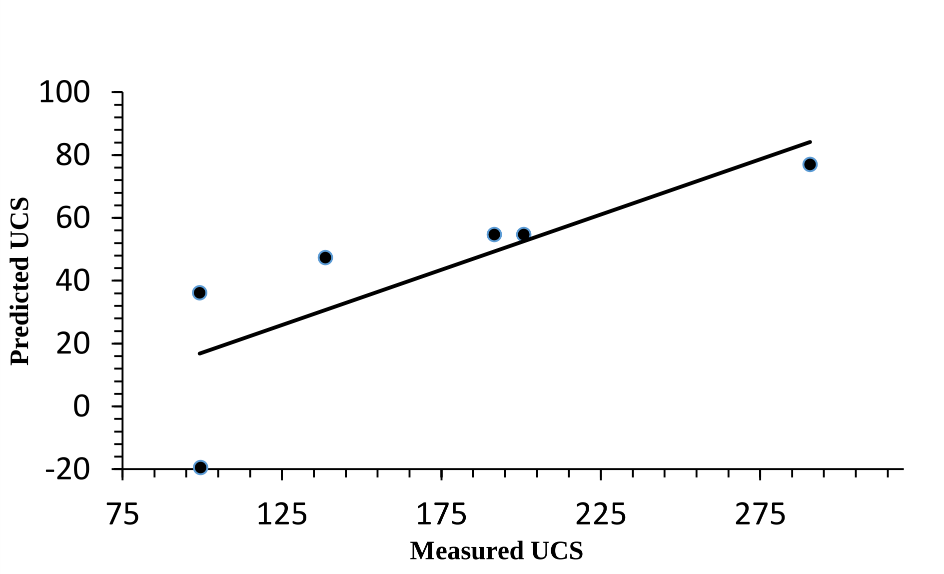

Fig. 5.3.3 UCS Analysis (2)

$$\text{Predicted UCS} = 0.3517x - 18.03, \quad \text{............ (5.3.3)}$$

Where, x= Density (Kg/m3)

With R=0.786

As the correlation coefficient suggests the predicted equation holds a good relation with the predicted and measured data.

5.3.4 Rahmouni et al. developed a linear regression analysis (section 2.5.3) to find out correlation between density and P-wave elastic velocity. The equation proposed as:

$$y = 1.2466x + 1.6065,$$

Where y= P-wave velocity (m/s)

x= Density (Kg/m3)

The predicted V_p values from the density was plotted against the measured values (fig. 5.3.4). There exists a trend of predicted V_p that compare favourably with the actual values though the magnitude varies. The relation obtained as:

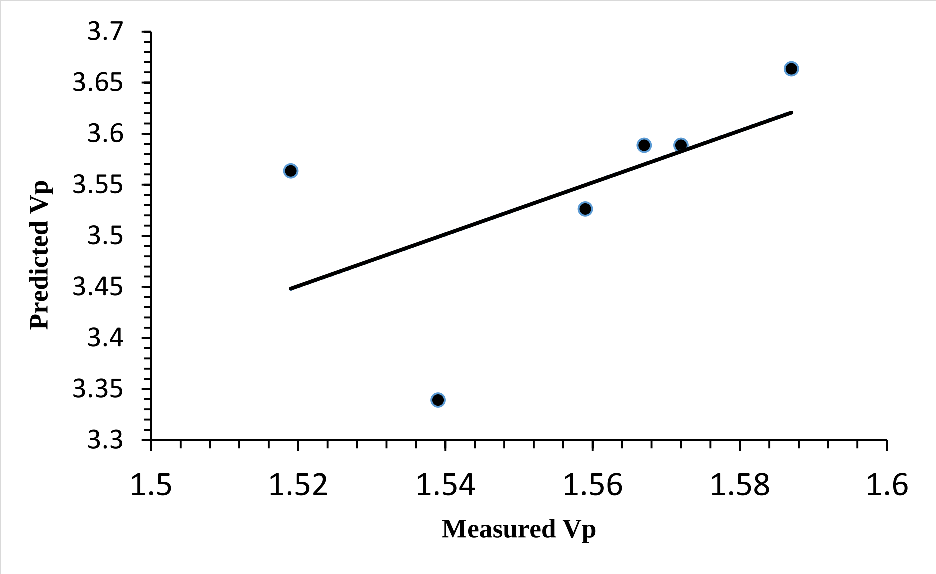

Fig. 5.3.4

V_p Analysis

Predicted V_p= 2.5353x - 0.403, ... (5.3.4)

Where x= Density (Kg/m3)

With R= 0.563

However the relation does not agree when the index values are low. The equation suggested by Rahmouni et al.is acceptable for high V_p values.

5.3.5 Soroush and Qutob approached a power regression analysis (section 2.5.2) to find out correlation between density and V_p. The equation proposed as:

$$y=-2E\text{-}08V_p^2 + 0.0002V_p + 1.9296,$$

Where, y= Density (Kg/m3)

The predicted density values from the V_p was plotted against the measured values (fig.5.3.5). There exists a trend of predicted density that compare favourably with the actual values though the magnitude varies. The relation obtained as:

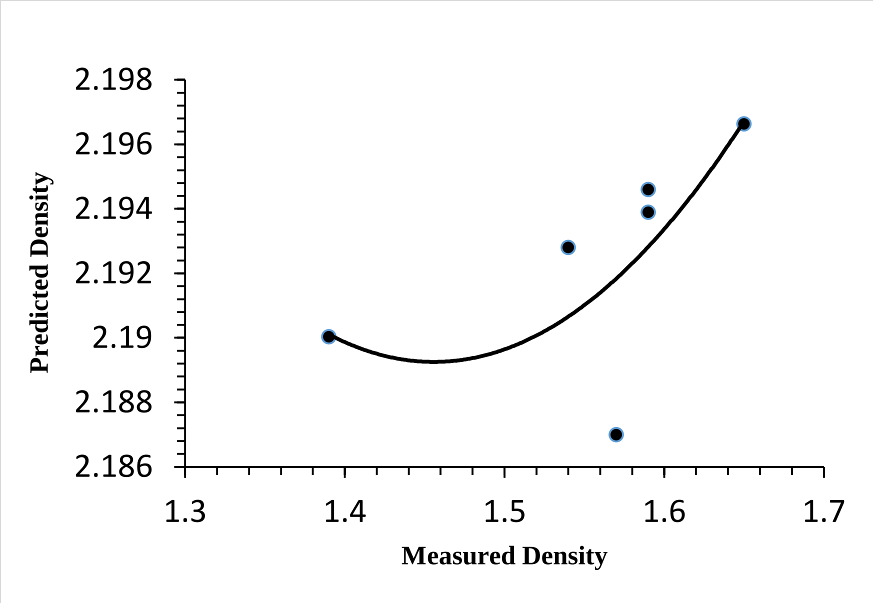

Fig.5.3.5

Density Analysis

$$\text{Predicted density} = 0.1977x^2 - 0.5755x + 2.6081, \qquad \text{.................. (5.3.5)}$$

Where, X= V_p(m/s)

With R= 0.678

The relation does not agree when the index values are low. The equation suggested by Soroush and Qutob is acceptable for high V_p values.

5.3.6 Soroush and Qutob also approached a power regression analysis (section 2.5.2) to find out correlation between density and Vs. The equation proposed as:

$$y=-610-8\ V_s^2 + 0.0004\ V_s + 1.9404$$

Where, y = Density (Kg/m3)

The trend (Fig. 5.3.6) of predicted density and actual density measured in laboratory obtained as:

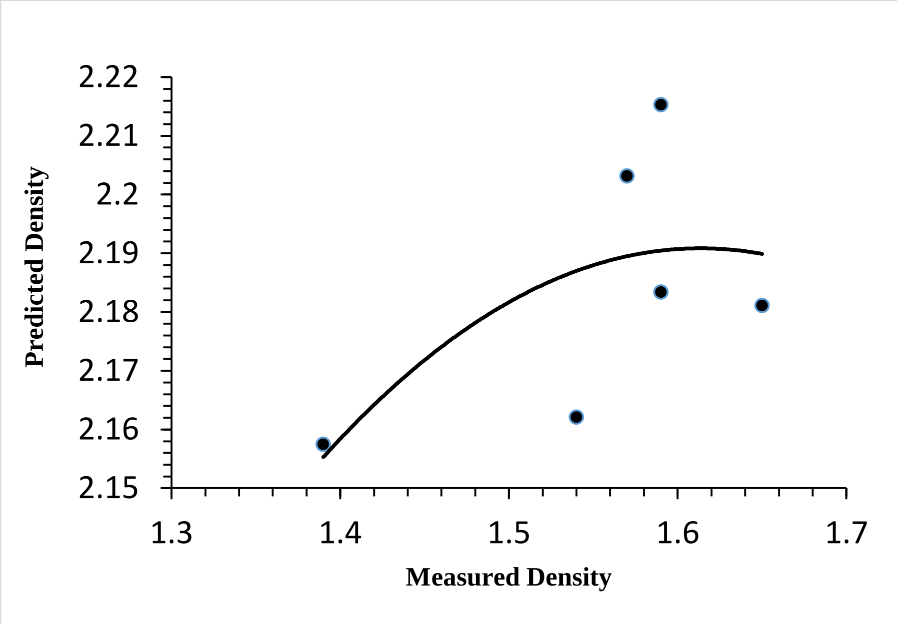

Fig.5.3.6

Density Analysis (2)

Predicted density = $-0.7113x^2 + 2.2955x + 0.3389$, ... (5.3.6)

Where X= V_s (m/s)

With R = 0.622

However the relation does not agree when the index values are high. The equation suggested by Soroush and Qutob is acceptable for low V_s values.

5.3.7 Soroush and Qutob approached a exponential regression analysis (section 2.5.2) to find out correlation between Tensile strength and V_p. The equation proposed as:

y=0.348e0.0004 Vp,

Where y = Tensile Strength ($б_t$) (MPa)

The predicted Tensile Strength values from the V_p was plotted against the measured values (fig.5.3.7). There exists a trend of predicted density that compare favourably with the actual values though the magnitude varies. The relation obtained as:

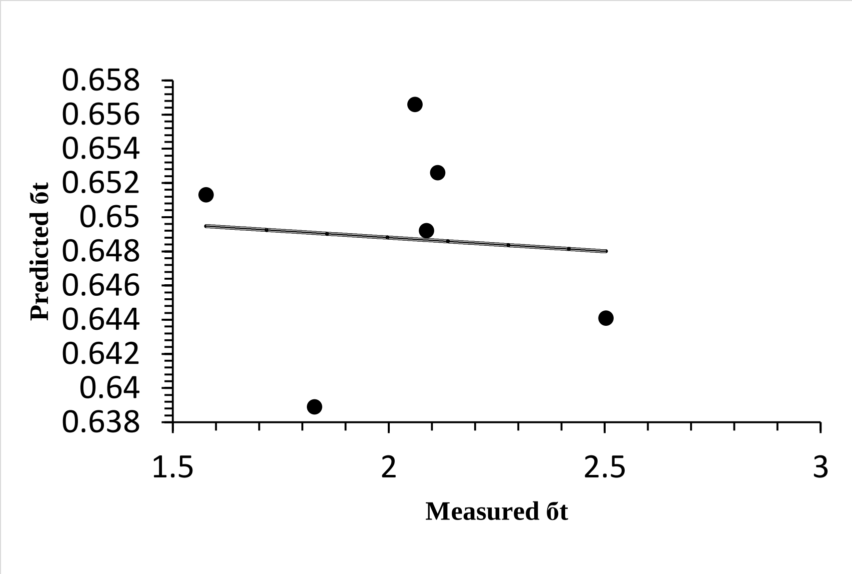

Fig.5.3.7 Tensile Strength analysis

…………5.3.7

Predicted Tensile Strength ($б_t$) = $0.652e^{-0.002x}$

Where x = P-Wave velocity (m/s)

With R= 0.077

As the correlation coefficient suggests the predicted equation do not hold satisfactory relation with the predicted and measured data.

CHAPTER 6

Conclusion

6.0 Conclusion

It is observed from this study that the coal samples collected for the study are from the Gondwana region. The Protodyakonov strength index of the coal samples vary unexpectedly due to different locations and weathering condition. The experimental results shows satisfactory correlation between the mechanical parameters of coal as per the aim of this study.

Whereas the experimental data in certain cases do not relate as good as is expected from the predicted propositions of previous investigation having similar objectives.

Based on these exercises, the following conclusions are made:

i. Coal samples collected belong to Gondwana Region

ii. The average Protodyakonov Strength Index is 100.5533.

iii. The average Tensile Strength is 2.0282 MPa.

iv. The average Density is 1555 Kg/m^3.

v. The average P-Wave and S-Wave is 1557.167 and 678 m/s respectively.

vi. The average Unconfined Compressive Strength is 16.67 MPa.

vii. The relation between Protodyakonov Strength Index and Unconfined Compressive Strength is equal to UCS = 0.2549x-8.957; where x= Protodyakonov Strength Index.

ix. The relation between Tensile Strength and P-Wave velocity is equal to $б_t = 0.652e^{-0.002x}$; where x = P-Wave velocity (m/s).

x. The best relation obtained between Unconfined Compressive strength and Density is $Y=0.0334e^{0.0039x}$; Where Y=UCS (MPa), x=Density (Kg/m3)

xi. The relation between Tensile Strength and S-Wave velocity is equal to $y = 3.5441e^{-8E-04x}$ where $y = б_t$, x = S-Wave velocity.

xii The relation between P-Wave velocity and Density is equal to Y=0.041x+36.832

Where, Y=Protodyakonov strength index,

x=Density (Kg/m3)

The analysis between measured and predicted UCS exhibited best relation with that proposed by Chaterjee et al (2013). The obtained equation was Predicted UCS = $5.5719x^{0.2647}$ Where

x= measured UCS, With R= 0.803

Soroush & Qutob (2011) approached a power regression analysis to find out correlation between density and V_p, and density and V_s. The obtained equation was

Predicted density = $0.1977x^2 - 0.5755x + 2.6081$, Where, X=measured density, With R= 0.678

Predicted density = $-0.7113x^2 + 2.2955x + 0.3389$, Where X=measured density, With R = 0.622

Rahmouni et al. **(** 2013 **)** also formulated a linear regression analysis (section 2.5.3) to find out correlation between density and P-wave elastic velocity. The obtained feasibility is
Predicted V_p= 2.5353x - 0.403, Where x= Density (Kg/m3), With R= 0.563

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